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KERMA TRANSMISSION THROUGH VARIOUS MATERIALS FOR a p(66)Be(49) NEUTRON BEAM.

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INTRODUCTION. During the design and construction of the Fermilab Neutron Therapy Facility (NTF) (Co76,Aw79) it was not possible to measure the dose attenuation properties of various shielding materials considered for use. Furthermore, no data were available for the highly penetrating p(66)Be(49) neutron beam being planned. (The preceding notation indicates that 66 MeV protons lose only 49 MeV in the Be-target, unless they undergo nuclear scattering). Thus, the design of the shielding and collimation system for the beam was based on Monte-Carlo calculations performed by R. G. Alsmiller (Al75) using a transport code and nuclear interaction models described elsewhere (Al74). The neutron energy spectrum was calculated by A. Van Ginneken (Va73) using published data for (p,n) reactions in thin Li and Be targets. These calculations resulted in the original design (Aw78): a combination of steel, Benelex and polyethylene-loaded concrete in a collimation system with a total thickness of 110 cm. This system proved to be adequate for shielding considerations, but its length, combined with a SAD of 153.2 cm (Aw78), placed too many restrictions on patient rotation and set-up. While designing a new system with shorter collimators and a longer 190 cm SAD (Aw79,Ro81), measurements were made of the kerma fraction transmitted through several materials actually used or considered for shielding, collimation or blocking. This note presents some of the results of these measurements.

EXPERIMENTAL METHODS. The measurements were made in air using an air-filled 1 cm^3 spherical ionization chamber (EGXX) having walls and collector made of A-150 tissue equivalent plastic (Sm77). An A-150 build-up cap brought the total wall thickness to 14 mm, which is close to the depth of dose maximum for this material in the neutron beam under study (Aw78,Aw81). The integrating circuits for both this ion chamber and the monitor chambers were controlled by a microcomputer (Aw78). This system led to uncertainties in precision of less than 0.5% of the readings. The charge collected was interpreted as being proportional to total kerma in A-150 TE plastic at that point in air.

Two beam geometries were used, within the limitation of the NTF layout. All materials were studied under a poor man's "narrow beam" conditions. The beam was first collimated to a field size of 6x6 cm^2 at 190 cm from the target, completely covering the chamber. The samples were located starting at the exit end of the collimator, 110 cm from the target, and building in thickness toward the ion chamber. The chamber was located on the beam axis at 190 cm or more from the target. This geometry resembles the "narrow beam" layout described by Attix et al. (At76) .

Lead and steel absorbers were also studied under what Attix et al. (At76) describe as "semi-broad beam" conditions. The beam was collimated to a field size of 19x19 cm^2 at 153.2 cm from the target, the position of the ion chamber. The samples, having a 30x30 cm^2 cross-section, were located starting at the chamber and building in thickness towards the source.

RESULTS. The materials tested were: polyethylene, polyethylene concrete (Aw78), Lipowitz low melting alloy (We70), lead, steel and tungsten.

The results for both narrow beam and broad beam geometries are given in Figs. 1 and 2, where the total kerma fractions transmitted are plotted versus thicknesses in cm and g cm^{-2},respectively.

The "narrow beam" attenuation curve for steel was in fact extended to a transmission of 2.4×10^{-3} using 61 cm of Fe (480 g cm^{-2}). This level was taken as an upper limit to the room background. Corrections to the observed transmission levels were made using this upper limit, and they are shown with arrows in Figs. 1 and 2.

DISCUSSION. The initial (very small depth) macroscopic neutron removal cross-sections were calulated for comparison. They are defined in units of cm^{-1} or $cm^2\ g^{-1}$ by the following expressions:

$$\Sigma = \rho\ N\ \bar{\sigma}\ A^{-1}\ [cm^{-1}]$$

and

$$\Sigma = N\ \bar{\sigma}\ A^{-1}\ [cm^2\ g^{-1}]$$

where N is Avogadro's number, A is the atomic mass, ρ is the density in g cm^{-3} ,and $\bar{\sigma}$ is the weighted average of the total cross-section in cm^2. The weighted mean was calculated using:

$$\bar{\sigma} = \frac{1}{c} \int_0^{65} k(E)\ \Phi(E)\ \sigma(E)\, dE$$

where

$$c = \int_0^{65} k(E)\ \Phi(E)\ dE,$$

k(E) is the neutron kerma for A-150 TE plastic (Al77,Ca80), σ (E) is the neutron cross-section (Hu58) ,and Φ (E) is the neutron energy spectrum. The kerma function is used in the weighing integrals because a kerma sensitive detector was used in the experiment. Φ (E) was taken as equal to $a\sqrt{E}\,\exp(-E/2.5)$+const. up to 66 MeV, an approximation to the incident spectrum based on physical considerations and measurements reported by Waterman et al. (Wa79) and Smathers et al. (Sm76). Small changes at the low end of the energy spectrum do not affect $\bar{\sigma}$ significantly. The photon dose component of the open beam is less than 5% of the total dose (Am77,Ku79). At small depths, calculations (Al74,Al75) estimate a photon contribution of about 10% to the total dose. Hence, this component does not affect the estimate of the initial attenuation length of the total kerma significantly.

Table 1 compares the calculated attenuation lengths, $\lambda=\Sigma^{-1}$ with those derived from the measurements using the initial slope of the narrow beam attenuation curves. The agreement between measurements and calculations is generally within 10%. This is considered satisfactory. Also, these macroscopic removal cross-sections are close in value to those measured for a d(50)Be neutron beam by Smathers _et al_ (Sm78).

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REFERENCES

Al74 Alsmiller, R.G. and Barish, J. ,1974, "Calculations Pertaining to the Use of Fast (50 MeV) Neutrons in Cancer Radiotherapy", Med. Phys. , 1 , 51.

Al75 Alsmiller, R.G., 1975, Oak Ridge National Laboratory. (Private communication).

Al77 Aslmiller, R.G. and Barish, J. ,1977. "Neutron Kerma Factors for H, C, N, O and Tissue in the range of 20-70 MeV." Health Phys. , 33 , 98.

Am77 Amols, H.I., Dicello, J.F., Awschalom, M., Coulson, L., Johnson, S.W. and Theus, R.B., 1977. "Physical Characterization of Neutron Beams Produced by Proton and Deuterons of Various Energies Bombarding Beryllium and Lithium Targets of Several Thicknesses". Med. Phys. , 4 , 486.

At76 Attix, F.H., Theus, R.B., Miller, G.E., 1976. "Attenuation Measurements of a Fast Neutron Radiotherapy Beam". Phys. Med. Biol. , 21 , 530.

Aw78 Awschalom, M. and Rosenberg, I., 1978. "Neutron Beam Calibration and Treatment Planning", Fermilab Internal Report TM-834.

Aw79 Awschalom, M., Grumboski, L., Hrejsa, A.F., Lee, G.M. and Rosenberg, I., 1979. "The Fermilab Cancer Therapy Facility: Status Report after 2.5 Years of Operation", I.E.E.E. Trans. Nucl. Sci. NS-26 , 3 , 3068.

Aw81 Awschalom, M. and Rosenberg, I., 1981. "Characterization of a p(66)Be(49) Neutron Therapy Beam: II.Skin Sparing and Dose Transition Effects", To appear in Med. Phys.

Ca80 Caswell, R.S., Coyle, J.J. and Randolph, M.L., 1980. "Kerma Factors for Neutron Energies below 30 MeV." Submitted to Radiat. Res.

Co76 Cohen, L. and Awschalom, M., 1976. "The Cancer Therapy Facility at the Fermi National Accelerator Laboratory, Batavia, Illinois, a Preliminary Report", Applied Radiology, 5, (6), 51.

EGXX EG&G Model IC-17, now made by Far West Technology, Goleta, Calif., 93017.

Hu58 Hughes, D.J., and Schwartz, R.B., 1958. Brookhaven National Laboratory internal report BNL-325, 2nd Ed.

Ku79 Kuchnir, F.T., Awschalom, M., Grumbowski, L.E. and Sabau, M.N., "Determination of the Sensitivity of a Mg-Ar Chamber to High Energy Neutrons by Use of Two Independent Methods". Workshop on Ion Chambers for Neutron Dosimetry. Rijswijk, NL.

Ro81 Rosenberg, I. and Awschalom, M., 1981. "Characterization of a p(66)Be(49) Neutron Therapy Beam: I. Central Axis Depth Dose and Off-axis Ratios". To appear in Med. Phys.

Sm76 Smathers, J.B., Otte, V.A., Smith, A.R. and Almond, P.R., 1976. "Fast Neutron Dose Rate vs. Energy for the d + Be Reaction - a Reanalysis", Med. Phys., 3, 45.

Sm77 Smathers, J.B., Otte, V.A., Smith, A.R., Almond, P.R., Attix, F.H., Spokas, J.J., Quam, W.M. and Goodman, J.L., 1977. "Composition of A-150 Tissue Equivalent Plastic". Med. Phys., 4, 74.

Sm78 Smathers, J.B., Graves, R.G., Wilson, W.B., Almond, P.R., Grant, W.H. and Otte, V.A., 1978. "Shielding for Neutron Radiotherapy Sources Created by Be (d,n) Reaction". Health Physics, 35, 807.

Va73 Van Ginneken, A., 1973. "Neutron Energy Spectra from Proton Bombardment of Thick Lithium Targets in the 50-180 MeV Energy Range". Fermi National Accelerator Laboratory, internal report TM-441.

Wa79 Waterman, F.M., Kuchnir, F.T., Skaggs, L.S., Kouzes, R.T. and Moore, W.H., 1979. "Energy Dependence of the Neutron Sensitivity of C-Co, Mg-Ar and TE-TE Ionization Chambers". Phys. Med. Biol., 24, 721.

We70 Weast, R.C., ed., 1970. "Handbook of Chemistry and Physics". Cleveland, Ohio: The Chemical Rubber Co., 51st Ed.

FIGURE AND TABLE CAPTIONS

Fig. 1. Kerma fraction transmitted through various materials for a p(66)Be(49) neutron beam. The abscissa is in cm of material. Arrows represent maximum corrections for room background.

Materials:

▩ polyethylene	▼ polyethylene-concrete
□ steel	● Lipowitz alloy
○ lead	△ tungsten

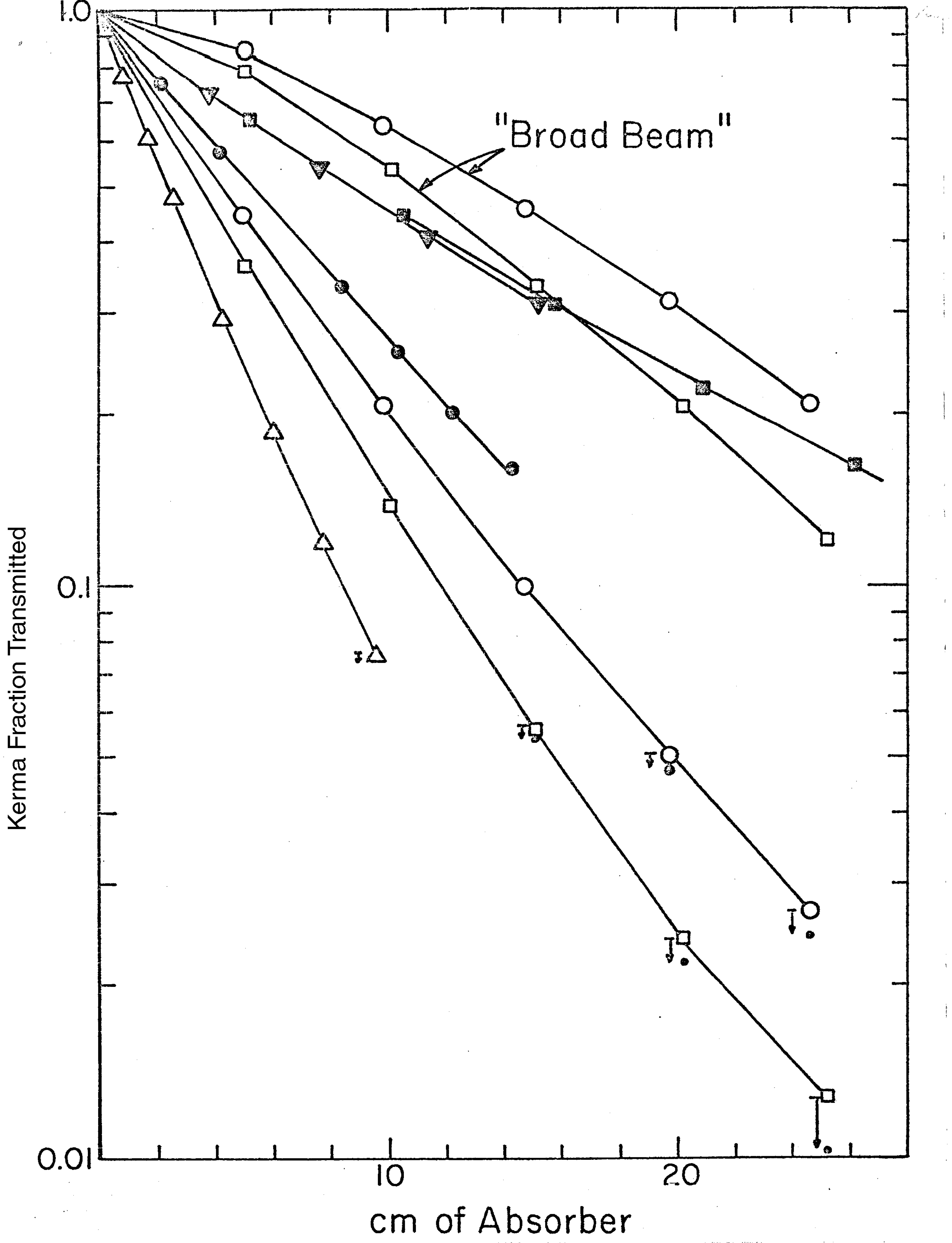
Fig. 2. Kerma fraction transmitted through various materials for a p(66)Be(49) neutron beam. The abscissa is in g cm^{-2} of material. Arrows represent maximum corrections for room background.

Materials:

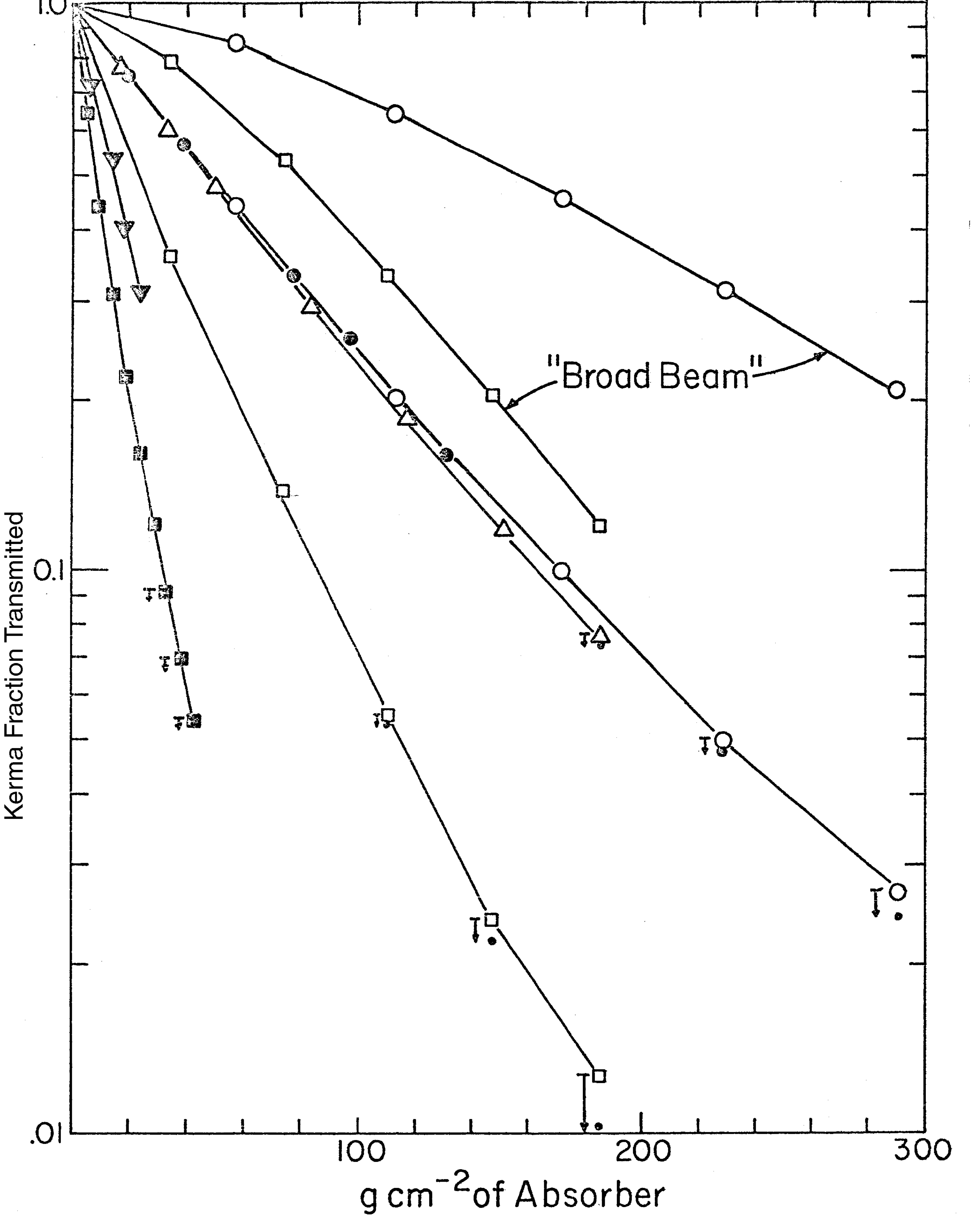
▩ polyethylene	▼ polyethylene-concrete
□ steel	● Lipowitz alloy
○ lead	△ tungsten

Table 1. Comparison of Measured and Calculated Attenuation Lengths.

MATERIAL	A	ρ	σ	Σ (CALCULATED)		λ(g cm^{-2})		λ(cm)	
		g cm^{-3}	barn	cm^2 g^{-1}	cm^{-1}	Calc	Meas	Calc	Meas
polyethylene	10.43	0.91	1.11	.0954	.0869	10.5	11.2	11.5	12.3
polyethylene concrete	32.26	1.59	2.33	.0512	.0814	19.5	20.3	12.3	12.8
steel	55.85	7.87	2.52	.0271	.214	36.8	38.5	4.68	5.0
Lipowitz alloy	186.8	9.39	4.79	.0158	.148	63.4	71.0	6.75	7.6
lead	207.2	11.35	4.99	.0145	.165	68.9	70.0	6.07	6.3
tungsten	183.8	19.3	4.75	.0156	.300	64.3	70.0	3.33	3.6



1.0
0.1
0.01
10
20
Kerma Fraction Transmitted
cm of Absorber
"Broad Beam"



Kerma Fraction Transmitted
1.0
0.1
.01
100
200
300
g cm^{-2} of Absorber
"Broad Beam"